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16. ABSTRACT

Two systems for exposing mice to 2,450-MHz electromagnetic fields are described. In a waveguide system, four mice were placed in a Styrofoam cage and exposed dorsally to circularly polarized electromagnetic fields. The temperature and humidity in the mouse holder were kept constant by forced-air ventilation. For 1-W input power to the waveguide, the average specific absorption rate (SAR) was determined by twin-well calorimetry to be 3.60 ± 0.11 (SE) W/kg in 27-g mice. The maximum SAR at the skin surface determined thermographically was 8.36 W/kg in the head of the mouse. The second system was a miniature anechoic chamber. Six mice were irradiated dorsally to far field plane waves. Copper shielding and high-temperature absorbing material were lined inside the chamber to accommodate the high input power. The air ventilation at the location of the mice was separately controlled so that any heating in the absorber would not affect the animals. For W-1 input power, the average SAR was 0.17 ± 0.01 W/kg and the maximum SAR at the skin surface was 0.41 W/kg in the animal when irradiated with body axis parallel to the E field; the SARs were 0.11 ± 0.01 W/kg and 0.64 W/kg respectively, when irradiated perpendicular to the E field.

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Systems for Exposing Mice to 2,450-MHz Electromagnetic Fields

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Two systems for exposing mice to 2,450-MHz electromagnetic fields are described. In a waveguide system, four mice were placed in a Styrofoam cage and exposed dorsally to circularly polarized electromagnetic fields. The temperature and humidity in the mouse holder were kept constant by forced-air ventilation. For 1-W input power to the waveguide, the average specific absorption rate (SAR) was determined by twin-well calorimetry to be 3.60 ± 0.11 (SE) W/kg in 27-g mice. The maximum SAR at the skin surface determined thermographically was 8.36 W/kg in the head of the mouse. The second system was a miniature anechoic chamber. Six mice were irradiated dorsally to far field plane waves. Copper shielding and high-temperature absorbing material were lined inside the chamber to accommodate the high input power. The air ventilation at the location of the mice was separately controlled so that any heating in the absorber would not affect the animals. For 1-W input power, the average SAR was 0.17 ± 0.01 W/kg and the maximum SAR at the skin surface was 0.41 W/kg in the animal when irradiated with body axis parallel to the E field; the SARs were 0.11 ± 0.01 W/kg and 0.64 W/kg, respectively, when irradiated perpendicular to the E field.

Key words: 2,450 MHz, exposure system, circular waveguide, anechoic chamber, mice, dosimetry

INTRODUCTION

In studying the biological effects of microwave radiation, simultaneous exposure of groups of animals to radiofrequency electromagnetic fields has been a common practice. Under normal laboratory conditions, the animals are housed in a group with water and food available ad lib. These conditions can cause serious dosimetry problems during exposure to electromagnetic fields since scattering and intensification of fields occur among the animals and the water bottle. The exposure of single subjects under properly controlled conditions in a large anechoic chamber can be prohibitively expensive. Guy and Chou [1975] and Guy et al [1979] have described two circularly polarized waveguide systems for exposing single small laboratory animals to 918- or 2,450-MHz electromagnetic fields. These systems have been used for chronically irradiating rats [Moe et al, 1975; Lovely et al, 1977; Guy et al, 1980]. To simulate free-field exposure, Guy [1979] also developed

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a miniature anechoic chamber for irradiating laboratory animals. Studies have been conducted in which rats [Lovely et al, 1978], and rabbits [Chou et al, 1982a; Chou et al, 1982b] were irradiated in this miniature chamber system.

In this paper, we present the modifications of these two systems for the exposure of small animals, such as mice, to 2,450-MHz electromagnetic fields. Groups of animals were housed separately and were placed at proper distances to minimize scattering of fields. The temperature and humidity in the location of the mice were maintained at a constant level. Dosimetry data on the two exposure systems are also presented.

METHODS AND RESULTS

Exposure System Modifications

It would be ideal from dosimetric considerations to expose mice individually in the center of a circularly polarized waveguide or a miniature anechoic chamber. However, when a large number of animals are to be studied, individual exposure of animals will greatly increase the cost. Since mice do not occupy much space, they can be placed at a relatively far distance from each other to minimize scattering among the animals. The mice must be housed separately since close contact of the animals can greatly intensify the SAR at the contact point. Therefore, we placed each mouse in a holder made of a polypropylene beaker inserted into a low-loss Styrofoam cage for exposure. Since the system was designed for short-term exposure, water and food were not provided. To keep the animals in a constant temperature and humidity environment, forced air ventilation at an air velocity of 6.37 m/min (equivalent to 23 liters/min through the 250-ml holder) was provided by small fans. This air velocity is the same as that in the environmentally controlled exposure system of Ho et al [1973]. The temperature was kept at 25 $\pm$ 1 °C and the relative humidity at 50 $\pm$ 10%.

Details of the modifications of both exposure systems are as follows:

Circularly polarized waveguide. The horizontally positioned circular waveguides, as described by Guy et al [1979], were placed vertically for the exposure from the top of four mice in each waveguide (Fig. 1). The mouse cage, as shown in Figure 2, provides space for comfortably housing four mice in the waveguide. The holes at the bottom of the polypropylene beaker and the acrylic cover allow air to flow through the space occupied by the animals. The mouse cage was placed at a distance of 5/8 of the length of the waveguide from the top of the waveguide where the transmitting transducer was located. At this position, the uniformity of the energy absorption in the animals is optimal. The lower part of the waveguide was wrapped with a plastic sheet and a muffin fan was attached to the bottom of the waveguide for air ventilation. The fan voltage was controlled by a variable transformer to adjust the air velocity through the mouse cage. The air flow in each empty mouse holder was measured in an extended tube above each mouse holder with an anemometer (Alnor, Type 8500). The mean air velocity was set at 6.37 m/min. The laminar flow pattern varied from 4.88 m/min at the edge, to 6.71 m/min at the center of the mouse holder. The upper part of each waveguide was connected to a counter weight system for easy separation of the waveguide.

Miniature anechoic chamber. Figure 3 shows the front view of this chamber, which was modified from the original design described by Guy [1979]. The inside of the chamber was lined with a copper sheet to prevent leakage of microwaves during high-intensity exposures. At the ventilation holes (6.35-cm diameter), copper screen mesh pads were soldered to the copper sheet. Near the wide side of the horn (Narda, model

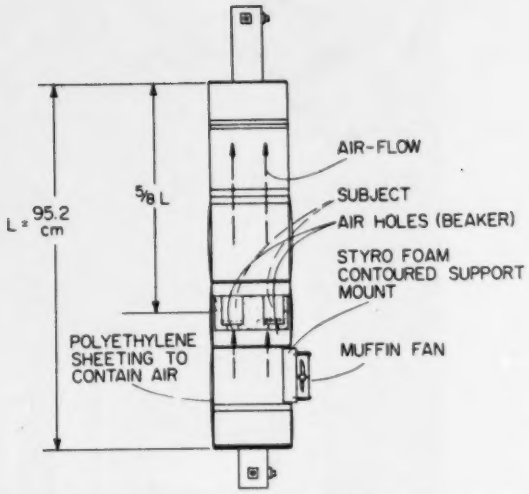

Fig. 1. Modified circularly polarized waveguide for exposing mice to 2,450-MHz electromagnetic fields in environmentally controlled condition.

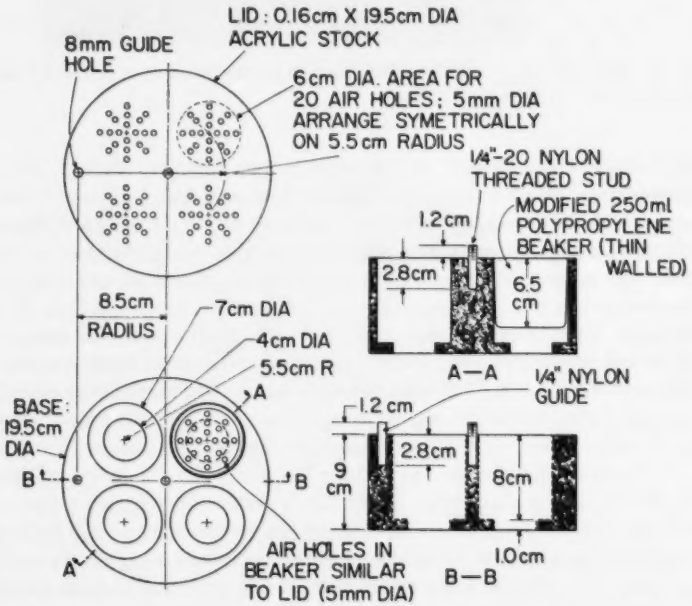

Fig. 2. Detailed diagram of the holding cage for exposing mice to microwaves.

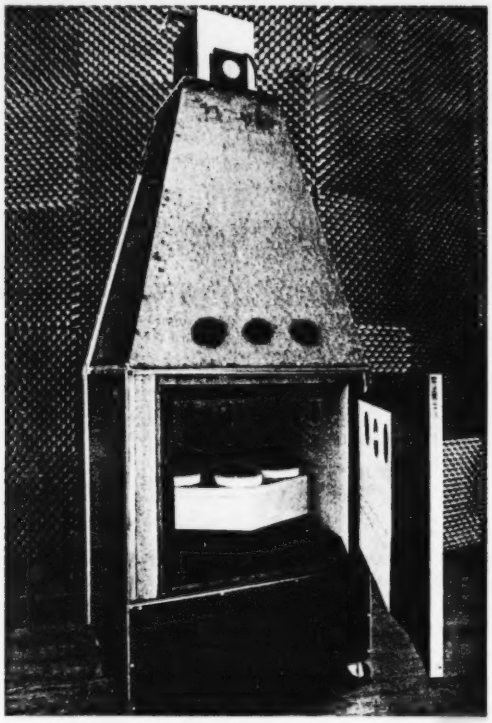

Fig. 3. Front view of the modified miniature anechoic chamber for exposing mice to high intensity microwave radiation (door open to show the mouse holder).

644), where the E field is maximum, a section (2.54 × 30.5 × 30.5 cm) of high-temperature, open-cell absorbing material (Eccosorb RM) was placed at each side of the horn in place of the original absorber (Eccosorb AN-77). Cooling of these absorbers was provided through 16 ventilation holes on each side of the chamber by two suction fans at the top. A three-mil plastic sheet separated the tapered section and the bottom of the chamber so that the upper section was ventilated independently from the lower section. There are three ventilation holes (6.35-cm diameter) on all four sides of the chamber above and below the plastic-sheet separation. The holes were cut at a 45-deg angle downward on the AN-77 absorber to minimize microwave leakage through these holes. The light bulbs used in the original design were removed since room light passes through the ventilation holes giving a more uniform lighting than obtained with the light bulbs.

Six mouse holders were placed in a hexagonal array as shown in Figure 4. A muffin fan was located at the outside of the lower section to provide air flow from the room through a 10 × 10 cm Styrofoam duct to the mouse holders. Air flow was adjusted to be identical to that in the circular waveguide, variation among the six mouse holders was less than 1.5%. Air from the mouse holders was ventilated through the holes at the top of the lower section of the chamber.

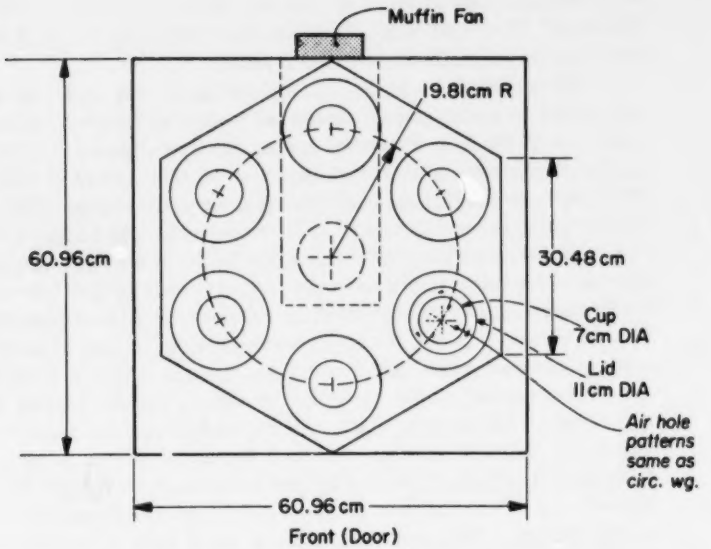

Fig. 4. Arrangement of mouse holders in the miniature anechoic chamber.

Dosimetry

The average power density inside the circular waveguide can be estimated by averaging the input power over the cross-sectional area of the waveguide. Therefore, for each watt of input power to the 20.3-cm diameter waveguide, the average power density in the waveguide is 3.1 mW/cm^2. In the anechoic chamber, the plane in which the mice were located (1.375 m from the horn) was divided into square-centimeter grids, and power density was measured in each square using an energy density meter (NBS EDMI-C4). The results of the measurement are very similar to those obtained previously [Guy, 1979] indicating that the modification did not alter the power distribution. For 1-W input power, the power density was 0.154 ± 0.003 (SE) mW/cm^2 at the locations of the mice.

The SAR in the mice was determined using two methods. The whole body average SAR was measured with a twin-well calorimetry system [Phillips et al, 1975]. The SAR distribution was determined thermographically [Guy, 1971].

Calorimetry. For the circular waveguide system, five mouse carcasses were used in each calorimetry run: one control and four exposed. One of the exposed mice and the control mouse were placed in a twin-well calorimeter. It was found that when mice (26.94 ± 0.27 g) were positioned radially with head toward or away from the center of the waveguide, the average SAR was 3.60 ± 0.11 (SE) W/kg normalized to 1-W input power in the waveguide. If the exposed mice were positioned perpendicular to the radial direction, the normalized SAR was 2.40 ± 0.09 W/kg. For the miniature chamber, seven mice were used in each calorimetry run, one control and six exposed. The six exposed mice were positioned either parallel or perpendicular to the E field and one of the irradiated mice was compared with the control mouse in the twin-well calorimeter. When the mice

were irradiated parallel to the E field, the SAR normalized to 1-W input power to the horn was 0.17 ± 0.01 W/kg. The SAR decreased to 0.11 ± 0.01 W/kg when the mice were oriented perpendicularly to the E field.

Thermography. Since mice are physically very small, the method of bisection used before in thermographic studies on models and animal carcasses can cause large errors due to the heat dissipation during the data acquisition process. We, therefore, decided to measure the SAR distribution at the skin surface of mice. Johnson and Guy [1972] have shown that the peak SAR is close to the average SAR where the radius of muscle sphere is small compared to the wavelength. The surface SAR should provide a close estimate of the internal SAR in mice. To avoid the messy process of removing hair from mice for better skin emissitivity, we used nude BALB/c mice. Figures 5–7 show the thermograms of mice exposed in the circular waveguide at three different orientations. Note in Figures 5 and 6, the SARs were higher in regions of mice that were near the center of the waveguide. The maximum normalized SAR was 8.36 W/kg in the head of the mouse exposed facing the center of the waveguide. Figures 8 and 9 show two representative thermograms of the mice exposed parallel and perpendicular to the electric field in the anechoic chamber. The SAR was quite uniform in the mouse exposed with body parallel to the E field. The highest SAR was 0.38 W/kg at the base of the tail. In Figure 9, the mouse body was perpendicular to the E field, and the SAR in the body was smaller than in a body exposed parallel to the E field. It should be noted that, in this mouse, the base of the tail was parallel to the E field. The induced current density was higher in the small cross-sectional area of the tail than the larger cross-sectional area of the body. Therefore, a high SAR of 0.64 W/kg was observed.

DISCUSSION

We have described two systems for exposing mice to 2,450-MHz electromagnetic fields. The circular waveguide system can be used to expose four mice simultaneously to circularly polarized electromagnetic fields. The miniature anechoic chamber system can be used to expose six mice at a time to plane wave electromagnetic fields. In the anechoic chamber system, the animals are separated from each other at a greater distance than in the circular waveguide. Therefore, multiple scattering among the animals in the circular waveguide is larger than in the anechoic chamber. However, the SARs in mice are well documented using the techniques of twin-well calorimetry and thermography.

Despite the scattering problem, there are several advantages of the circular waveguide system over the anechoic chamber system. The advantages make the circular waveguide system a better choice for exposing a large number of mice to electromagnetic fields for the study either of biological effects or hyperthermia for cancer therapy. The advantages are:

1. More energy efficient: The average SAR was 21 times higher when mice were exposed in circular waveguide than in the anechoic chamber for the same input power. This efficiency is important if a large number of animals are to be exposed, since smaller and less expensive power sources may be adequate.

2. Less orientation dependent: The difference in SAR between mice positioned in orientations was somewhat smaller in the circularly polarized waveguide (ie; 3.6 and 2.7 W/kg in circular waveguide versus 0.17 and 0.11 W/kg in anechoic chamber).

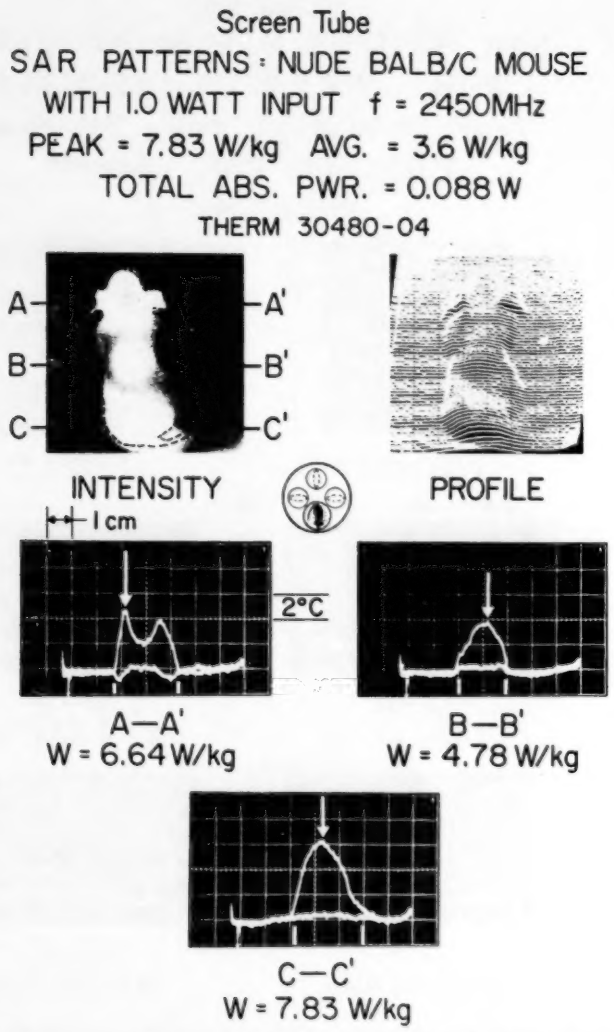

Fig. 5. Surface thermograms and calculated SARs for mouse exposed to 2,450-MHz microwaves with head away from the center of a circularly polarized waveguide.

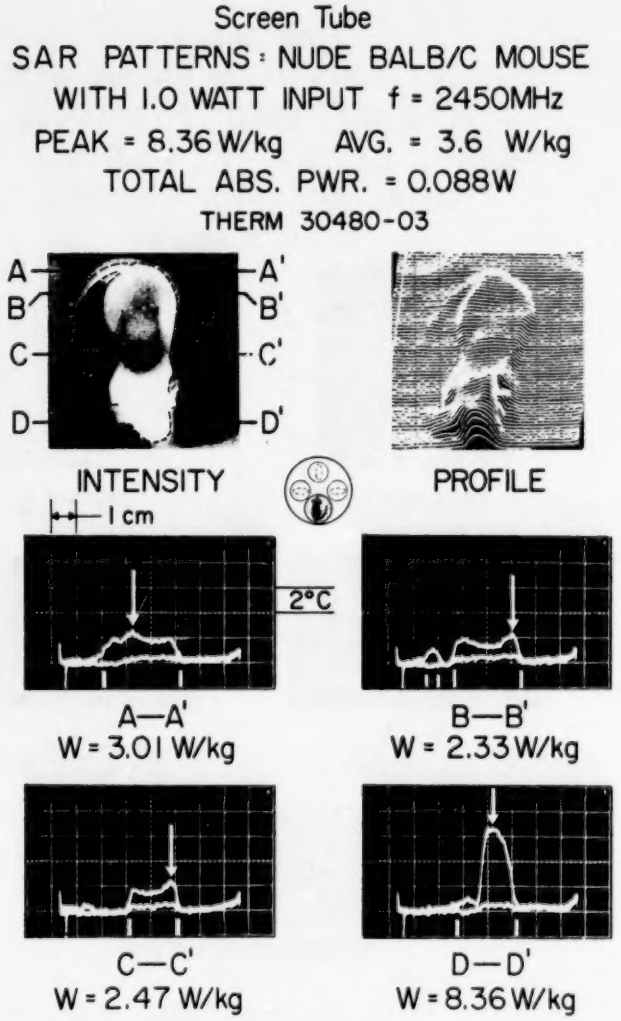

Fig. 6. Surface thermograms and calculated SARs for mouse exposed to 2,450-MHz microwaves with head toward the center of a circularly polarized waveguide.

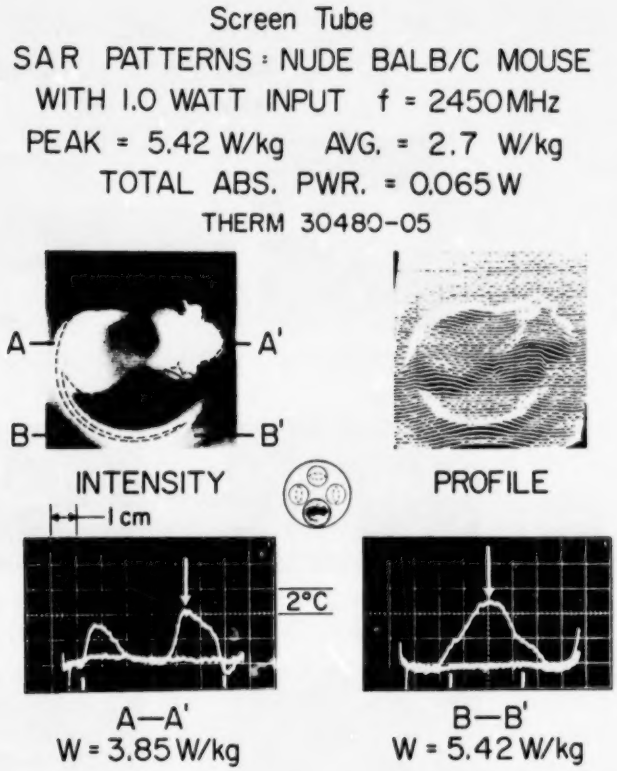

Fig. 7. Surface thermograms and calculated SARs for mouse exposed to 2,450-MHz microwaves with body perpendicular to the radial direction in a circularly polarized waveguide.

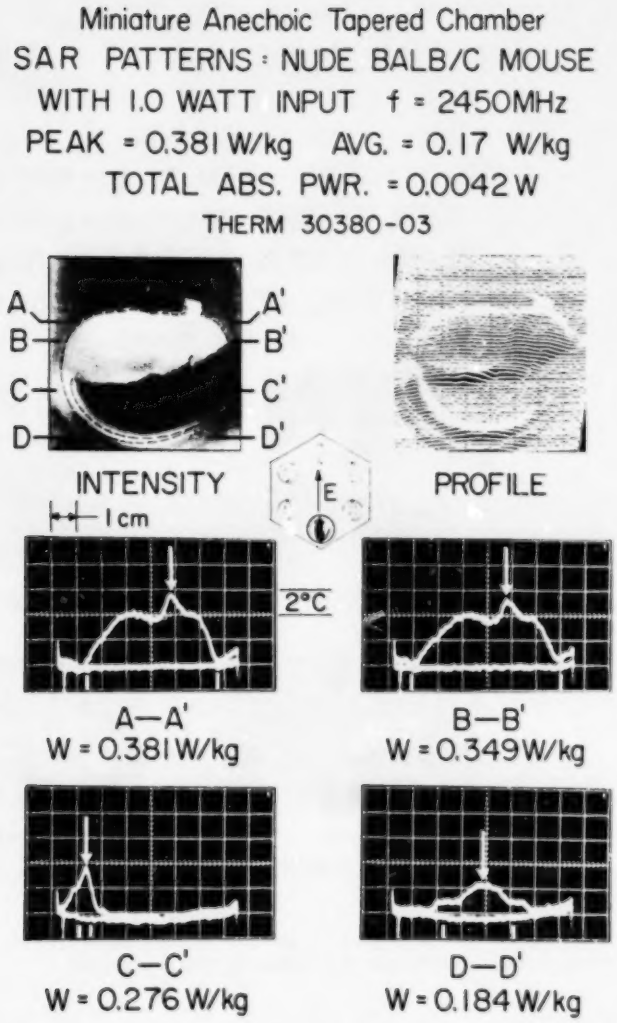

Fig. 8. Surface thermography and calculated SARs for mouse exposed to 2,450-MHz microwaves in the miniature anechoic chamber with body axis parallel to the E field.

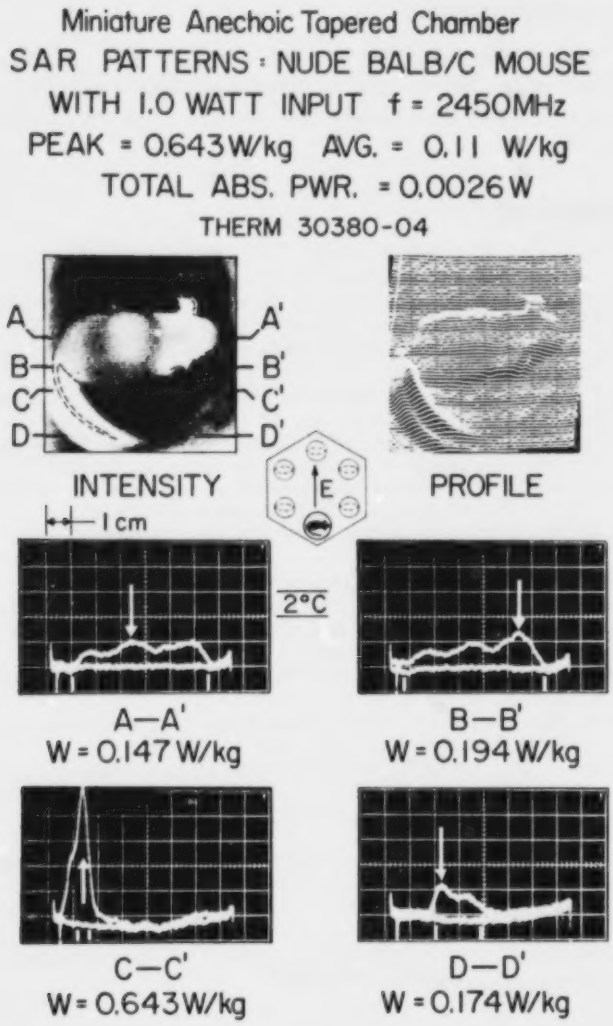

Fig. 9. Surface thermography and calculated SARs for mouse exposed to 2,450-MHz microwaves in the miniature anechoic chamber with body axis perpendicular to the E field.

3. Less space needed: The waveguide requires 324 cm^2 to expose four mice and the anechoic chamber occupies 5,519 cm^2 for six mice. Therefore, 11 times more space is needed for exposing a single mouse in the chamber than in the waveguide.

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